SYNOPSIS OF THE PROPOSED RESEARCH

TITLED

Theoretical Studies on Non-Linearity of Optical Fiber, its Remedies and Applications

For the degree of Doctor of Philosophy in Physics with permission from the department of physics , faculty of Science L.N.M.U, Darbhanga, 846008

Submitted By

Mr. DEEPAK KUMAR

Pat Roll No.22150036 (2021-22)

Under the supervision of

DR. SANJAY BHAGAT

Assistant Professor,

Department of Physics

S.B.S.S. COLLEGE BEGUSARAI, 851101

(A constituent Unit of Lalit Narayan Mithila University,Darbhanga,)

Forwarded
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15.04.24

Prof. & Head
Univ. Dept. of Physics
L.N.Mithila University, Darbhanga

Dean,
Faculty of Science
L.N.M.U., Darbhanga

1.Introduction

The advent of the laser in 1960 gave birth to a new field of optics because in the modern high capacity core communication network uses optical fibers to transmit one point to another as modulated light pulse. The optical fiber is a dielectric cylindrical waveguide made up of low-cost material silica [1].The basic phenomenon responsible for guiding the light pulses inside the optical fiber is total internal reflection [1].In modern day light pulse is a high intensity LASER light. The intense light pulse is changes the refractive index of the medium, due to its inelastic scattering with atoms. It is called nonlinear optics because the response of atoms to intense electromagnetic fields could no longer be taken to be linear in the electric field. So polarization is occur for the medium this is the cause of nonlinearities of fiber so fiber non linearities fall into two general cateogaries [2] The first category arises from modulation of the refractive index of silica by intensity changes in the signal (Kerr effect). This gives rise to non-linearities, such as self-phase modulation (SPM) [3], whereby an optical signal alters its own phase; cross-phase modulation (XPM) [4], where one signal affects the phases of all other optical signals and vice versa; and four-wave mixing (FWM) [5], It is well known that chalcogenide glass transmit in the infrared wavelength and possess very high values of the third order nonlinearity [5] This makes them very useful for many applications such as optical switching, Raman amplification, wavelength conversion and broadband super continuum generation.etc. In this work I will try to solve the pulse propagation equation and shrodinger equation for get the solution of nonlinear polarization polarization vector with using free online available software for its better computational simulations. Next part I will try to discuss about how to minimize or remedies polarizability poroperties of optical fiber medium. Finally I will discuss about how many nonlinearity fiber applications are possible.

II THEORETICAL DEVELOPMENT AND MATHEMATICAL MODELING OF NON LINEAR EFFECT IN OPTICAL FIBER

II(1) LITERATURE REVIEW FOR THE PROPOSED RESEARCH WORK

The first nonlinear optical effect to be predicted was two-photon absorption, by Maria Goeppert Mayer for her PhD in 1931, but it remained an unexplored theoretical curiosity until 1961 and the almost simultaneous observation of two-photon absorption at Bell Labs[6] and the discovery of second-harmonic generation by Peter Franken et al. at University of Michigan, both shortly after the construction of the first laser by Theodore Maiman.[7] However, some nonlinear effects were discovered before the development of the laser.[8] The theoretical basis for many nonlinear processes were first described and which is also understand by the following mathematical explanation. When the electromagnetic waves are propagating through the core of the optical fiber then, the core of optical fiber may be get polarize and it is depending on its intensity of incident wave and dielectric of core materials.

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If the week incident electromagnetic wave propagating through the optical fiber then the dielectric polarization $\vec{P}$ can be relating with electric field $\vec{E}$ of the electromagnetic wave as:

$\vec{P} = \epsilon_0 \chi^1 \vec{E}$.....(1)

Where ϵ_0 permittivity of free is space and χ^1 is the first order susceptibility or linear susceptibility. Mechanism of this polarization phenomenon are understanding from the following fig.(a) and fig.(b).,Here Fig (a) representing charge model of an atom when electromagnetic wave is propagating and incident on an atom of core material then the components of electric field of the incident wave try to oscillate the charge model of atom according as the fig. (b)

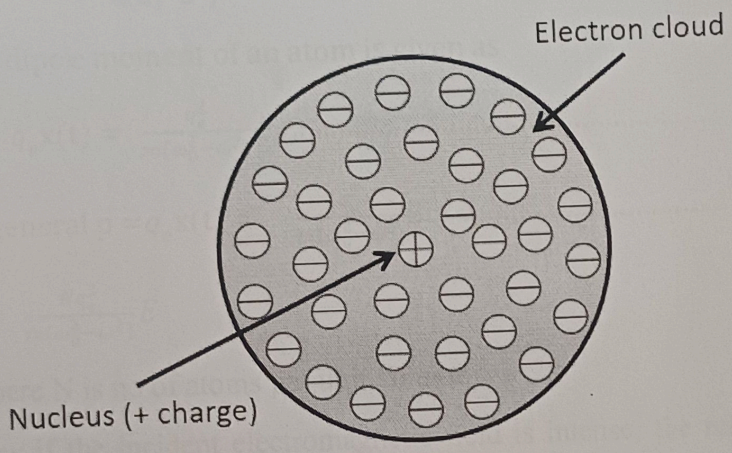

Fig. a

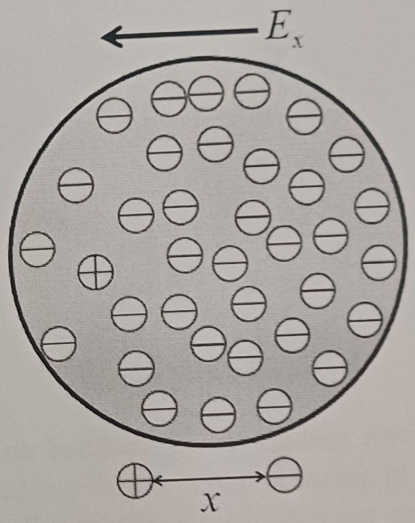

Fig. b

Here the centre of mass of positive and negative charges of atom is get displacement of x due to the incident electric field so, responsible external electric force is $E_x \cdot q_e$ and restoring force is –Kx due to the oscillating behaviour of charges .

Now according to the Newton's law of motion:

Net force= External Force + Force of restoration

$m\frac{dx^2}{d^2t} = q_e.E_x$-Kx.....(2)

or $\frac{dx^2}{d^2t} + \omega_0^2 x = \frac{q_e}{m}.E_e$.....(3)

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Where $\omega_0 = \sqrt{\frac{K}{m}}$ is the natural frequency of oscillation

Assume applied electric field $E_x = E_0 \exp^{(-j\omega t)}$.....(4)

The displacement x(t) due to the applied field also change harmonically in the steady state and try a solution as

$x(t) = B.\exp^{(-j\omega t)}$ .....(5)

Subsititing (5),and (4) in equation (3) we get

$B = \frac{E_0 q_e}{m(\omega_0^2 - \omega^2)}$

And $x(t) = \frac{q_e}{m(\omega_0^2 - \omega^2)} E_x$.....(6)

The dipole moment of an atom is given as

$p = q_e x(t) = \frac{q_e^2}{m(\omega_0^2 - \omega^2)} E_x$.....(7)

In general $p = q_e x(t) = \frac{q_e^2}{m(\omega_0^2 - \omega^2)} E$.....(8)

$P = \frac{N q_e^2}{m(\omega_0^2 - \omega^2)} E$

Where N is no of atoms per unit volume

Now if the incident electromagnetic field is intense, the relation between the restoration force and the displacement is nonlinear, and thereby, the electron cloud oscillation is not harmonic [9]. In this case, the relation between the dielectric polarization P and the electric dipoles are nonlinear, which can be generalized as [9]:

$\mathbf{P = \epsilon_0(\chi^1 E^1 + \chi^2 E^2 + \chi^3 E^3 ....)}$.....**(9)**

Where $\chi^{(j)}$ is the j^{th} order susceptibility. $\chi^{(j)}$ is also a tensor of rank j+1. $\chi^{(1)}$ is first-order susceptibility and is related to the linear refractive index. The second order susceptibility χ^2 generates the second-harmonic and sum-frequency terms, which is cause of nonlinear properties of refractive index of the medium.

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II(2) WORK PLAN AS PER OBJECTIVE AND METHODOLOGY

II (2a) Pulse propagation in optical fibers

The wave propagation in dispersive nonlinear media is governed by the fundamental theory of electromagnetic wave propagation underpinned by the Maxwell's equations [1]. Using Maxwell's equations, one can easily show that:

$$\nabla\times\nabla\times E = -\frac{1}{c^2}\frac{d^2E}{dt^2} - \mu_0\frac{\partial^2 P}{\partial t^2} \quad \text{.....(9)}$$

Where μ_0 is permeability of the free space.

For the nonlinearity in optical fiber, the induced dielectric polarization $\mathbf{P}(\mathbf{r},t)$ consists of two parts such as [1]:

$$\mathbf{P}(r,t) = \mathbf{P_L}(r,t) + \mathbf{P_{NL}}(r,t) \quad \text{.....(10)}$$

Where $\mathbf{P_L}$ and $\mathbf{P_{NL}}$ are the linear and nonlinear parts which are given as:

$$\mathbf{P_L}(r,t) = \varepsilon_0 \int_{-\infty}^{\infty} \chi^{(1)}(t-t')E(r.t')dt'$$

And

$$\mathbf{P_{NL}}(r,t) = \varepsilon_0 \int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \chi^{(3)}(t-t_1, t-t_2, t-t_3) : E(r,t_1)E(r,t_2)E(r,t_3)dt_1dt_2dt_3$$

II(2b) Nonlinear Schrödinger equation

From equation (9) and (10), we can represent the wave equation as:

$$\nabla^2 E - \frac{1}{c^2}\frac{\partial^2 E}{\partial t^2} = \mu_0\frac{\partial^2 P_L}{\partial t^2} + \mu_0\frac{\partial^2 P_{NL}}{\partial t^2}, \quad \text{.....(11)}$$

To solve the wave equation in (11), we adopt several simplifying assumptions including [1]:

(a) The nonlinear part of the dielectric polarization P_{NL} is treated as a small perturbation to the linear part P_L;

(b) A scalar approach is adopted, i.e. the optical field is assumed to maintain the polarization along the length of the fiber; and

(c) A quasi-monochromatic assumption for the optical field

II(2b .1)Mathematical tools for solving the propagation equation

1. Numerical approximation method
2. Analytical approximation methods

Deepak kumar
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II(2c)COMPUTATIONAL SIMULATION THROUGH SCI LAB (OPEN SOURCE)

Scilab is a free and open-source, cross-platform numerical computational package and a higlevel, numerically oriented programming language. It can be used for signal processing, statistical analysis, image enhancement, fluid dynamics simulations, numerical optimization, and modeling, simulation of explicit and implicit dynamical systems and (if the corresponding toolbox is installed) symbolic manipulations. Scilab is one of the two major open-source alternatives to MATLAB, the other one being GNU Octave. Scilab puts less emphasis on syntactic compatibility with MATLAB than Octave does, but it is similar enough that some authors suggest that it is easy to transfer skills between the two systems. Scilab is a high-level, numerically oriented programming language. The language provides an interpreted programming environment, with matrices as the main data type. By using matrix-based computation, dynamic typing, and automatic memory management, many numerical problems may be expressed in a reduced number of. code lines, as compared to similar solutions may be using traditional languages, such as Fortran, C, or C++. This allows users to rapidly construct models for a range of mathematical problems. While the language provides simple matrix operations such as multiplication, the Scilab package also provides a library of high-level operations such as correlation and complex multidimensional arithmetic. The software can be used for signal processing, statistical analysis, image enhancement, fluid dynamics simulations, and numerical optimization. Scilab also includes a free package calledXcos (a fork of Scicos based on Modelica language) for modeling and simulation of explicit and implicit dynamical systems, including both continuous and discrete sub-systems. Xcos is the open source equivalent to Simulink from MathWorks. As the syntax of Scilab is similar to MATLAB, Scilab includes a source code translator for assisting the conversion of code from MATLAB to Scilab. Scilab is available free of cost under an open source license. Due to the open source nature of the software, some user contributions have been integrated into the main program.

III Remedies and applications: Remedies and applications part will discuss in detail in thesis

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Prof. & Head
Univ. Dept. of Physics
L.N.Mithila University, Darbhanga

Deepak Kumar
13-04-24